GloTraM TB9 user guide

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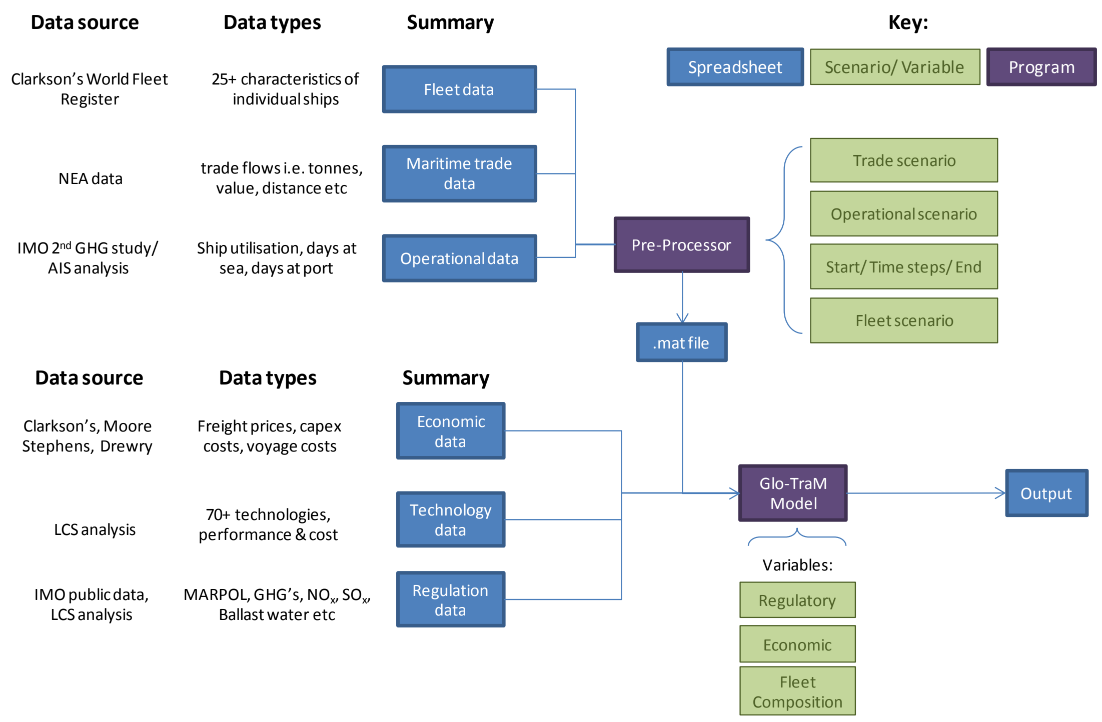
Contents

Executive Summary

This user guide explains the basic elements of the Glo-TraM-2 model and offers step-by-step instructions for how to install and operate it. There are two aspects to Glo-TraM-2: the pre-processor, and the model itself. The pre-processor summarises the information into a form that the model can read, and then the model simulates shipping demand and outputs over a specified time period.



Low Carbon Shipping – A Systems Approach

Is a research project which started in January 2010. It is majority funded by the RCUK energy (UK government research funding) programme (£1.7m over 3 years), but also supported financially and in-kind by a number of industry partners including Lloyd's Register, Rolls Royce, Shell and BMT.

The project is producing a holistic analysis of the global shipping system in order to investigate, using data and modelling, how shipping might change in response to developments in fuel prices and environmental regulation (on emissions of SOx, NOx, PM, CO_2). Areas of particular focus are the possible trajectories of the CO_2 emissions from the shipping industry, where these emissions might be apportioned and to whom (ship types and stakeholders), and what the costs and impacts of substantial emission reduction of the shipping industry might be.

The period covered by the modelling is 2010-2050 and its scope includes all the major contributor vessel types and trade flows. The research work in general is divided into 6 work packages, from which outputs are collated to provide inputs into the holistic model GloTraM (Global Transport Model):

1. Modelling the global shipping system
2. Technologies for low carbon shipping
3. Shipping, ports and logistics
4. Shipping economics and life cycle costs
5. Regulation, policy and the shipping stakeholder space
6. Operation for low carbon shipping

A conceptualization of the modeling framework that we use for our work on shipping efficiency and emissions can be seen in Figure 1. Each box describes a component within the shipping 'system'. The feedbacks and interconnections are complex and only a few are displayed on this diagram for the sake of clarity. This conceptualization allows us to break down the shipping system into manageable analysis tasks, ensure that the analysis and any algorithms are robust, and then connect everything together in order to consider the dynamics of the whole system.

The project's research approach is multi-disciplinary in that it mixes engineering, economics and logistics algorithms and data. However, a quantitative modelling approach can only describe those parts of the shipping system which are numerical in nature. As a result, much of the supporting work underpinning the assumptions used in the modelling are standalone and in-depth qualitative analyses (e.g. into market barriers, full cost accounting, end to end supply chains, regulatory and policy frameworks, operation and maintenance procedures etc). These are presented and discussed in associated documentation.

Glo-TraM-2 has been developed in Matlab (for algorithms and user interfaces), Excel (for data input and output) and a number of different database platforms. The purpose of this document is to guide a user in:

- the origins of any input data,
- how to setup and use the model and

- how to inspect the results.

The details of the model's theoretical basis, derivation of assumptions, validation and outputs are presented in other documents.

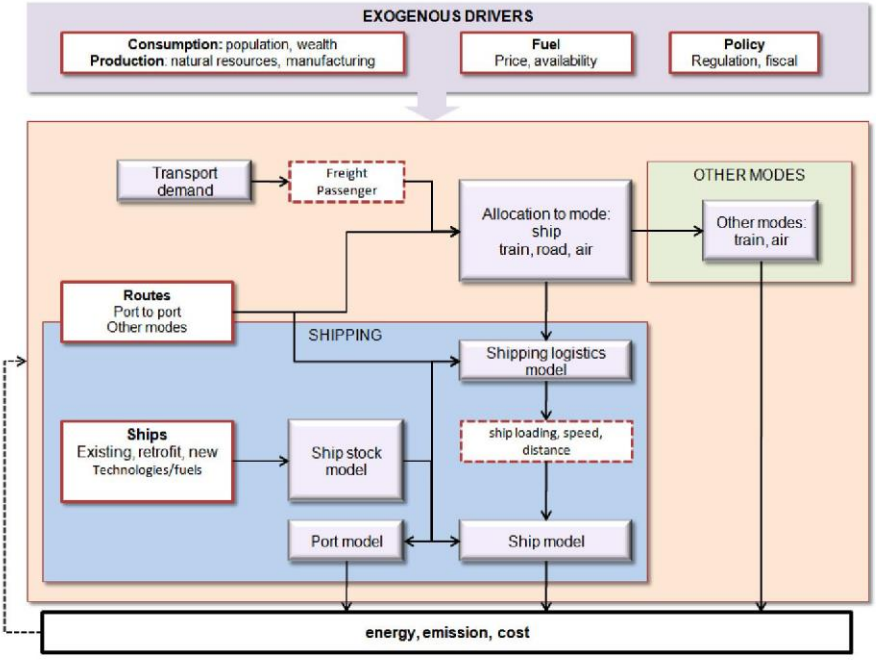


Figure 1: Conceptualisation of the shipping system model

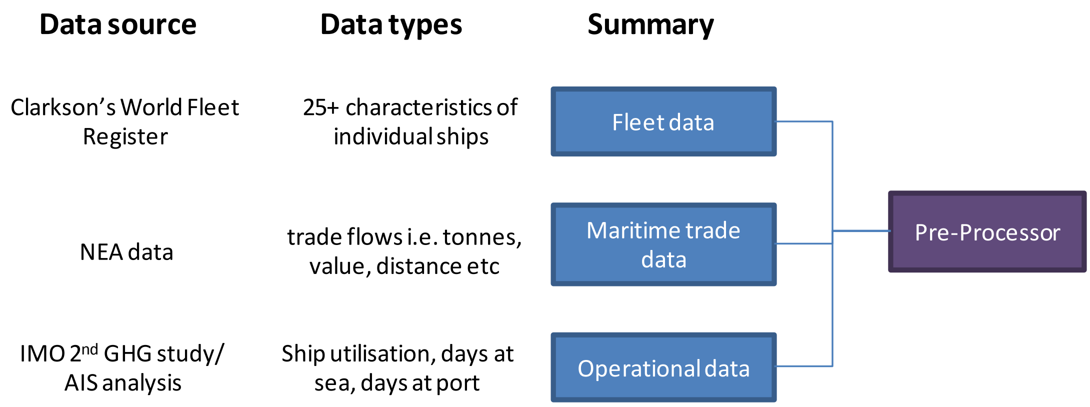
1. Glo-TraM-2 Pre-processor

We work with trade, operational and fleet data at the highest resolution and level of detail that we can obtain. However, that level of detail is not always necessary for use in shipping system modelling and used in its raw form can detract from accuracy of results and make the model computationally expensive to run.

We have therefore developed a pre-processor which collects characteristics for a fleet of ships, groups countries into trade regions, and groups commodities. An example of the former is ships of a certain type, size and age (e.g. crude tankers, in size range 280,000 - 320,000 tonnes built between 1995 and 2000). An example of the latter is all liquid bulk commodities traded between Europe and North America.

The pre-processor is run from a user interface and excel spreadsheets. These spreadsheets contain detailed information on size and type ranges. It is currently being modified so that different commodity categories can be collated in different ways and matched to different aggregations of ship types (e.g. wetbulk may be selected to either include or not include crude, products and other tankers).

1.1 Input data



Fleet data

- **Why this is important:** Detailed information of ship characteristics are necessary for technical calculations and for meaningful modelling and analysis
- **Current source:** Clarksons World Fleet Register
- **Data the source contains:** Specifications of the world fleet (dimensions, machinery, cargo capacity and handling etc). There are differences in definition and extent between this database and the Lloyds Fairplay data with pros and cons to both.
- **Reason for using this source:** UCL have research and consultancy licenses for Clarksons data, and it is extensively used in the ship owner and operator

community (due to its authority on which ships are actively trading). It also has a relationship with Clarksons Research's other major product, the Shipping Intelligence Network.

- **Alternative sources:** Lloyds Fairplay data
- **Comment/current issues:** The register is incomplete. Some technical details (fuel consumption, auxiliary machinery, lightship displacement) are sparsely populated or may be absent. Where these variables are necessary for meaningful modelling and analysis they have been generated using interpolation, trends or a third party source (discussed in validation documentation REF). In total 25 variables are used to characterize each individual ship, and the structure allows further technical calculations and variables to be included as required.

Trade and transport demand data

- **Why this is important:** Trade is the driver of demand for shipping and an important component of the modelling. For in-depth understanding of the links between shipping and GDP, detail beyond the level of global aggregate trade forecasts is also needed.
- **Current source:** NEA database of world trade flows
- **Data the source contains:** Over 200,000 datapoints per year (100 commodity categories all country-country or lower level maritime trade flows of imports and exports). The data is both historical (using UNCTAD comtrade and Eurotat as the main sources) as well as forecast into the future (2050)
- **Reason for choosing the source:** NEA's agent based model has already been used extensively on EU transport research and modelling (REF). UCL-Energy has been able to develop their own marine distance calculator which can be used in conjunction with NEA's distance estimates to characterise maritime trade in terms of tonnes, value, distance and tonnekm.
- **Alternative sources:**
- **Comment/current issues:**

Operational data

- **Why this is important:** Parameters like ship utilisation and days spent at sea and in port are fundamental to the calculation of shipping activity and emissions.
- **Current source:** The IMO second GHG study
- **Data the source contains:** capacity utilisation for 42 ship types
- **Reasons for using this source:** This is the most comprehensive estimate in the public domain and is supported by historical AIS analysis and expert opinion.
- **Alternative sources:**
- **Comment/current issues:** These values have been assembled into our own database structure for use in our analysis and modelling. Some values have been broken down further using other public domain sources. For example, capacity utilisation is broken down into dwt usage and ratio of ballast to laden voyage time whereas ship speed is endogenised in the modelling and analysis or controlled explicitly.

- It is possible to substitute your own assumptions about operational data by changing any values and saving these in a new spreadsheet.

1.2 Setting up and running the pre-processor

- Run the file MCRInstaller.exe from the "GloTraM TB9 distribution" folder and follow the instructions for installation. If there are any problems, see the readme file. This installs the Matlab run-time environment on your computer and so you need administrator/installation privileges.
- Setup a new root directory on your computer e.g. C:\GloTraM
- Copy the folder "master model" from "GloTraM TB9 distribution" to the new root folder e.g. to produce C:\GloTraM\master model
- Open master model to find preprocessor.exe and the directory C:\GloTraM\master model\data
- Run preprocessor.exe. If it runs successfully the preprocessor user-interface will come up (Figure 2). This may take a few seconds, so be patient.

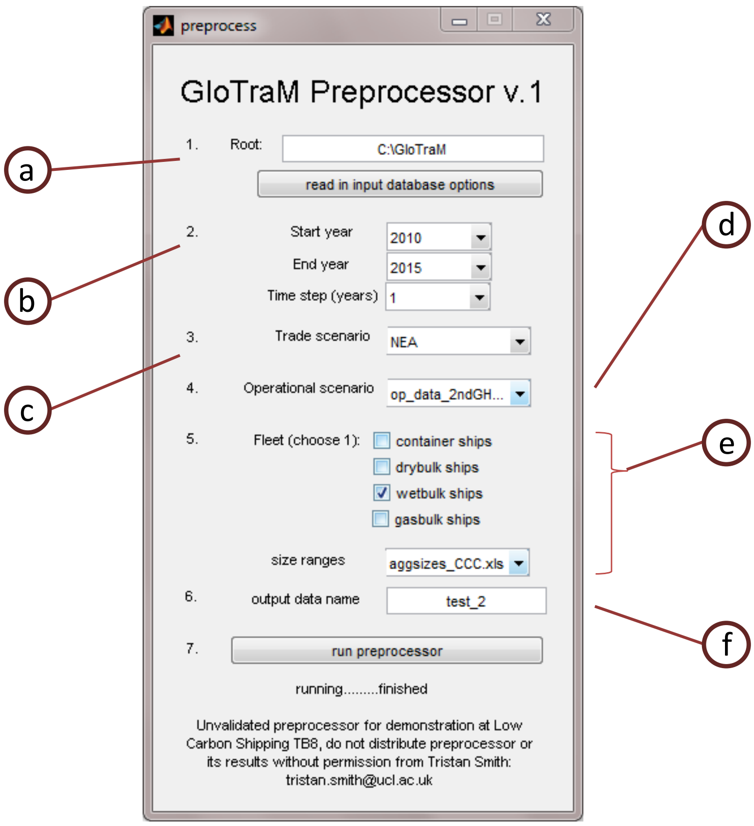


Figure 2: The user interface for pre-processing the model data

- In the “Root:” text-box, enter the name of new root directory that you have set up e.g. C:\GloTraM

- Click the button "read in input database options". This should reference the files from the folder C:\GloTraM\Master model\data and place the names of these into the drop down menus. If successful, the text in the drop-down menus will change from “Pop-up Menu” to the names of the databases.
- To test, try setting up the pre-processor with the following variables:
    - Start year = 2010,
    - End year = 2015,
    - Time step = 5,
    - Trade scenario = NEA,
    - Operational scenario = op_data.xls,
    - Fleet = wetbulk,
    - Size ranges = aggsizes_ccc,
    - Output data name = test_1
- Click the button "run preprocessor"
- If the preprocessor starts, the dialogue below the "run preprocessor" button will say "running…". The command window will also show some warnings, but don’t worry, as these don’t mean that the preprocessor has crashed. In terms of time to run, the pre-processor should take 30 seconds to a minute. When the process is successful, the dialogue box will say "....finished", otherwise an error readout will appear in the command window.
- If you get an error read out, please email me (Tristan Smith) the details and I will do my best to diagnose and remedy.

1.3 Adjusting variables/inputs for the pre-processor

a) Root

This is the location where the root directory is stored (the folder which contains the folder ‘master model’), if you followed the directions above, it should be C:\GloTraM.

b) Start, end and time-step

The start year, end year and time-step determine the length and resolution of the simulation. The start year must be a year for which there is corresponding fleet and trade data. At present, this is only 2010. The end year can be any year after the start year. If start year and end year are the same, the model will run for a single time-step.

All calculations are performed on annualised average figures so the time-step must be an integer.

The global fleet is disaggregated by age and the time-step determines not only the time period between calculations, but also the age range of each age disaggregation. For example, if the time-step is 5 years, the model will run one set of calculations for every 5 year period (2010, 2015, 2020…) using average characteristics of the fleet across the time-step e.g. (0-5 year old ships, 5-10 year old ships, 10-15 year old ships etc). Computational time is therefore highly sensitive to time-step.

c) Trade Scenario

The trade scenario describes the macro-economic assumptions behind the trade data and therefore the transport demand data from which the shipping activity is derived. For example, the trade scenario describes a certain level of population and GDP growth in each of the world's countries, as well as resource availability and manufacturing capacity and from this the commodities traded between a pair of countries have been calculated. The trade scenario describes aggregations of 100 commodities traded between all of the world's countries in terms of their annualised mass flows and annualised values.

There is only one trade scenario supplied with the model at present, but the ability to choose from a greater number will be available shortly.

d) Operational Scenario

Operational specifications describe how the fleet is being used. The data can be found in spreadsheets in the location root\master model\data\op_data.

The data (e.g. number of days active per year, days at port per nautical mile at sea, number of ballast days per loaded days) have been compiled from a variety of sources, for each ship type's ships of a specific representative size (repdwt). The values can be altered and the spreadsheet saved with a new name to represent different scenarios, which it is possible to select in the preprocessor user interface.

e) Fleet selection and size ranges

In GloTraM, the fleet is modelled as aggregations of different ship types and sizes. Whilst distinctions are made within each type and size aggregation for different ship ages, within each age category the properties are determined from the mean or the mode of the aggregation. Separating the fleet into a greater number of aggregations will increase the definition and specificity of the fleet's properties but will also increase the computational effort required.

The data describing the minimum and maximum dwt of each size category can be found in root\master model\data\sizes. The values can be altered and the spreadsheet saved with a new name to represent a different calculation, which it is possible to select in the preprocessor user interface.

f) Output data

The output data is produced as a .mat file which can be read into the model. The file will be given the name entered into the text box so that you can identify a specific preprocessor run in the model interface. The data is stored in the root\master model\data\outputs\preprocessed.

2. GloTraM

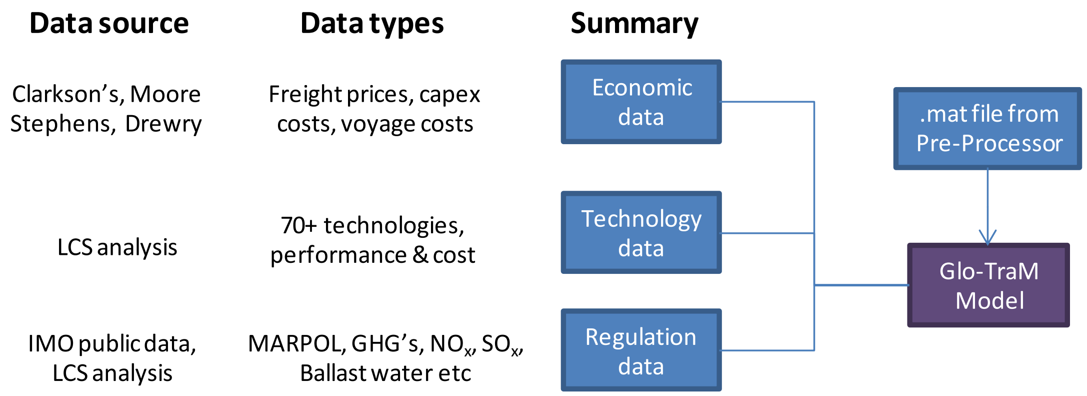
We have developed a model of the shipping system (GloTraM – Global Transport Model) which represents, quantitatively, all the components shown in the conceptualization of the shipping system in Figure 1. It is the embodiment of quantitative and qualitative research across all six of the work packages in Low Carbon Shipping – A Systems Approach.

GloTraM models the shipping industry for specified time periods in the future. Starting at a baseline year, it steps forward one time-step at a time, evolving the global fleet's technical and economic specification in response to exogenous inputs like regulation, trade and fuel price scenarios. This enables, for the first time, the consequence of a range of foreseeable scenarios to be established - in terms of their impacts on shipping's costs and emissions.

The model can be run at a range of levels of detail/disaggregation e.g.:

- High levels of detail and high levels of aggregation. Useful for policy makers, to understand the impacts of carbon pricing (or other policy measures) on overall carbon emissions and costs e.g. freight rates and the price of new ships.
- Low levels of detail and high levels of *dis*aggregation i.e. to the level of individual ships. Useful for industry stakeholders, to find out their optimum investment and operational choices in times of uncertain fuel prices and rapidly changing regulation.

2.1 Input data



Regulation data

- **Why this is important:** The shipping industry operates under a backdrop of regulation, from national to regional as well as international (through the IMO). It is important to incorporate this backdrop into the modelling and analysis
- **Current source:** a compilation of various sources in the public domain including IMO and EU policy documents

- **Data this includes:** GHG regulation as well as other regulation which will impact both the capital costs and efficiency of ships (MARPOL, SO_x/NO_x, Ballast Water etc)

Economic data

- **Why this is important:** to understand the economic drivers of the shipping industry
- **Current source:** an aggregate of a variety of sources, from the Clarkson's Shipping Intelligence Network (research and consultancy licenses), Moore Stephens and Drewry.
- **Data this includes:** freight prices (time charter and voyage charter prices), sunk costs (operating costs, new-build costs, maintenance costs) and voyage costs (different fuels and carbon prices). We hold historical data for a number of different shipping markets, and also produce forecasts of activity to apply to the models when the economic parameters are not already part of it.

Abatement option data

- **Why this is important:** to understand what will increase shipping's efficiency and reduce its emissions.
- **Current source:** a mixture of sources, including IMO data and LCS analysis**.** Specific analysis by LCS includes research on naval architecture and marine engineering (an £800k investment), as well as quantifying the impact on ships (e.g. loss of dwt, change in hull parameters, stability etc)
- **Data this includes:** Around 70 abatement options, from technical (e.g. waste heat recovery, air lubrication) to operational (e.g. weather routing, trim optimisations). Each option is characterised in terms of its costs (initial purchase cost, installation cost and through life) and performance for a range of different ship types. The database also captures how performance and cost scale depending on ship size, installed power, speed, operating MCR etc, and whether these relationships are linear or non-linear.

2.2 Setting up and running Glo-TraM-2

- This next set of instructions assumes you have already followed the setup instructions for the preprocessor. If you have not, go back and follow these before attempting this.

- From your root folder e.g. C:\GloTraM\master model\, run the file GloTraM_main.exe (this should launch the user interface for the model, Figure 3)

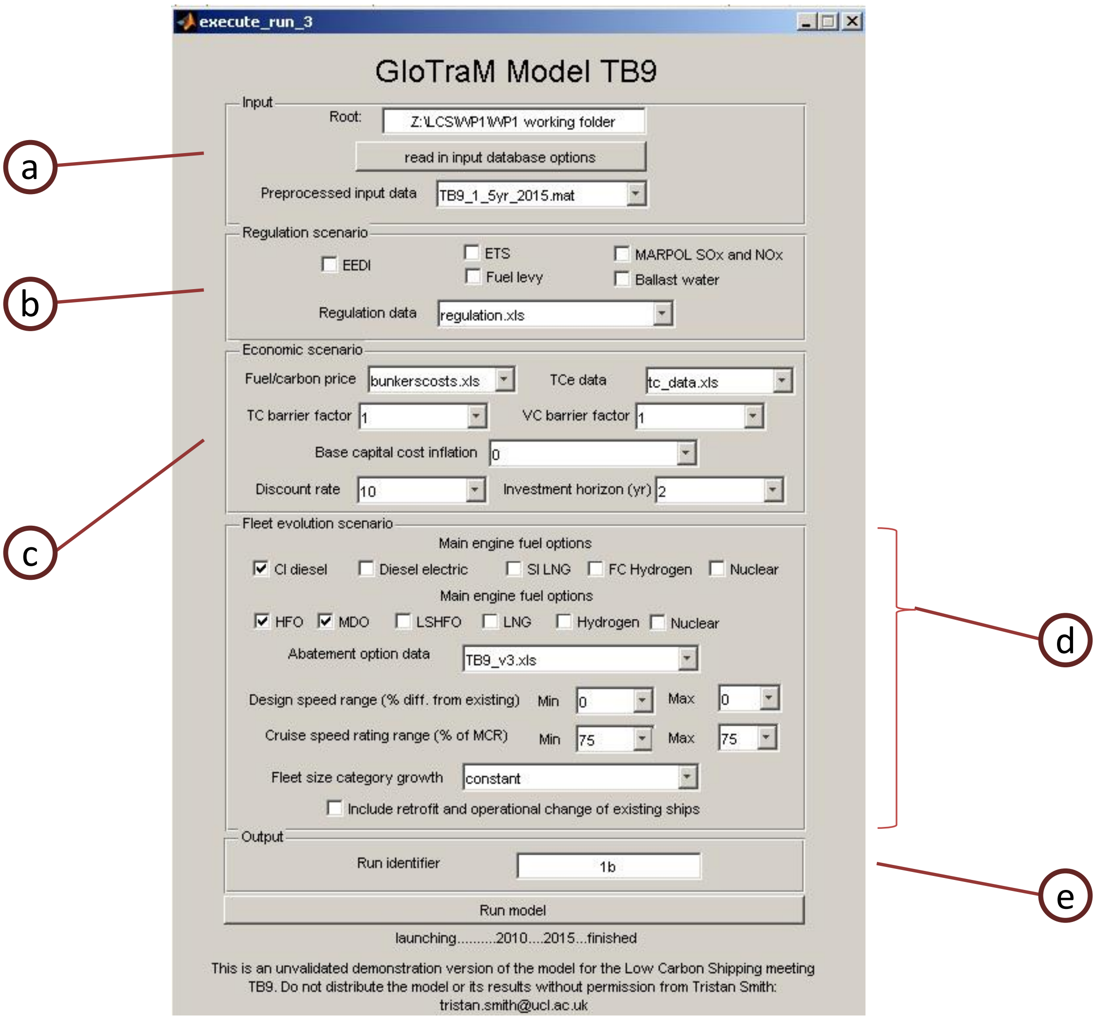


Figure 3: the user interface for the GloTraM model

- In the “Root:” textbox, enter the same address as you did in the preprocessor user interface e.g. "C:\GloTraM”
- Click the button “read in input database options”, which as before should populate the pop-up menus. If successful, the text in these will change from “Pop-up Menu” to the names of databases.
- Try setting up with the following:
  - Input
    - In “preprocessed input data”, select the file that you've just created in preprocessor i.e. 'test_1'
  - Regulation scenario
    - don't tick any of the options for regulation scenarios and leave regulation data as the default (regulation.xls)
  - Economic scenario
    - leave fuel/carbon price and TCe data as the defaults (bunkercosts.xls and tc_data.xls)
    - leave the TC barrier factor and VC barrier factor both at their defaults i.e. 1
    - set Base capital cost inflation to 0%
    - set Discount rate to 10%
    - set Investment horizon to 1 year

    - Fleet evolution scenario
        - just tick HFO on the fuel options and leave others unticked
        - set Abatement option data to TB9_v3.xls
        - set Design speed range to a min of zero and a max of zero
        - set the Cruise speed rating range to a min of 75 and a max of 75
        - set the Fleet size category growth to “constant”
        - do not tick the box “include retrofit and operational change for existing fleet”
    - Output
        - enter Run identifier as 1
- Click "run model". As before, if this runs it will say "launching....2010...2015...finished"
- If the finished message displays, then the model should have created an output spreadsheet with the results, which you can find at C:\GloTraM\master model\data\outputs\test_1\1.xls
- If you get an error read out, please send me (Tristan Smith) the details of the error and I will do my best to diagnose and remedy.

a) Input

Root is the location where the root directory is stored (the folder which contains the folder ‘master model’), if you followed the directions above, it should be C:\GloTraM.

Any preprocessed input data files should appear for selection from the drop down menu, using the filenames that were entered into the “output data” dialogue box. Create and chose different input files depending on what ship type you are interested in modelling and the operational parameters, aggregation parameters, size category and time parameters you want to use in your simulation.

b) Regulation Scenario

Check boxes give the user choices of what regulatory instruments to include when carrying out a run. The data file describing the different regulations “Regulation data” (e.g. different stringencies) is selected from the drop down menu. The files in the drop down menu come from “root”\Master model\data\inputs\regulation

Inclusion of a carbon price can be done either through selecting the ETS or the Fuel levy, at present the impact on shipping economics are identical because the carbon price is determined exogenously (using the data in bunkercosts.xls). In the future, the carbon price will be able to be calculated endogenously and limited by a specified cap.

Whilst the inclusion of MARPOL SOx and NOx regulation and Ballast water as IMO regulation has been decided upon and defined, these options are added so that users can compare results to explore sensitivities and to observe the impact of different levels of stringency (e.g. variations in the date at which the global 0.5% sulphur cap is introduced).

c) Economic Scenario

The economic scenario describes the exogenous data that are used to determine the ship owner's costs and revenue. Input data for the core costs, the fuel and carbon price per tonne and the time charter equivalent day rate are selected as input spreadsheets from the drop down menu. The files can be manually modified and saved as alternatives and come from "root"\Master model\data\inputs\costs.

There are some additional terms that are also used:

- **TC barrier factor**, this is a factor that represents the effect of market barriers in setting the time charter prices. A value of 1 is equivalent to there being a perfect market and zero barriers. For now, this is the default and only option.
- **VC barrier factor**, similar to the TC factor this represent barriers in the voyage charter market and has been set at the default and only option
- **Base capital cost inflation**, is the inflation rate as applied to sunk costs such as newbuild prices and the cost of low carbon technology.
- **Discount rate**, is the interest rate used to discount future profits.
- **Investment horizon**, is the time horizon over which the profitability of an intervention (change in design speed, fuel or adoption of low carbon technology) is assessed. For now, main machinery alternatives are assessed over the life-time of the ship, however this assumption can be modified manually outside of the user-interface.

d) Fleet Evolution Scenario

This section defines the operation and technical parameters used in the consideration of how the fleet will evolve.

The **main engine** machinery and fuel options need to be selected 'in harmony' and there is nothing from stopping the user from selecting incompatible pairs (e.g. diesel electric with hydrogen fuel) so care must be taken. The combination options are currently:

- CI (Compression Ignition) diesel with
    - HFO and MDO (must include both)
    - Option of LSHFO
- Diesel electric with
    - HFO
    - MDO
    - LSHFO
- SI (Spark Ignition) LNG with
    - LNG
- FC Hydrogen with
    - Hydrogen (a reformed LNG FC option will be added shortly)
- Nuclear with
    - Nuclear

Whatever overall combination of machinery/fuel options is selected, the CI diesel with HFO and MDO must be included because this is what is used in the existing fleet.

Abatement option data defines the ship impact database filename. This database is the overall output to GloTraM from LCS WP2 and includes characterisations of technical and cost impacts for a number of different technology/operational abatement

(energy efficiency) options that can be applied to a ship. This database (worksheet 'all_ships') can be found in:

Root\master model\data\inputs\carbon_abate

The .xls file also contains basic data defining the different main machinery options: their costs, specific fuel consumption, impact on a ship's dwt and compatability with different fuels (worksheet 'main_machinery').

The detailed values in the excel file should not be edited manually because it is produced using a number of algorithms and assumptions which produce data that can be scaled for ships of different size, type, design speed etc. Obtaining the values in the database is a work in progress. Many of the values in the database are currently sourced from outside the consortium (e.g. IMO publications). New updated spreadsheets will be issued over time as research into specific options in WP2 is completed, and can be added to this folder for use in the model.

However, if you do not agree with the inclusion of some technologies or want to test what happens if they are left out of consideration, the "use" column can be specified (1 = include, 0 = ignore).

Speed is an important variable both as a design parameter and an operational parameter. Whilst GloTram includes algorithms to calculate the optimum speed, in practice the design and operating speed may be constrained by parameters that are outside the scope of the optimisation. As a result, the user has two means to constrain the range of design and operational speeds that will be considered by the model:

- **Design speed range** allows the user to set the upper and lower bound vales according to a % change relative to the baseline ship's design speed (a newbuild in 2010). E.g. if the design speed is 15knots and +/- 10% is specified in the user interface, the model will calculate the optimum speed for newbuilds in a given year (taking into account economic and regulation data/specifications) from between the range 13.5kts to 16.5kts.
- **Cruise speed rating range** allows the user to set the upper and lower bound of the %MCR that a main engine is run at. Design speed is specified at 75% MCR (75% of the maximum power output of the main engine), the min and max values are similarly set relative to maximum power output. Therefore, if you do not want the simulation run to deviate from operation at anything other than a ship's design speed set min/max both to 75. If you want to allow for the possibility of slow steaming (which will be determined as a function of the freight rate/fuel price) then provide a lower value than 75%. Cruise speed refers to the average speed that the ship travels at when not manoeuvring etc.

Fleet size category growth determines how the transport demand for new ships is distributed across the ship size category range. For example, what portion of the newbuilds in any one year are VLCCs, Suezmax, Aframax, Seaway or Handy. At the moment, there are only two choices:

- Optimise determines what size to build according to the size range which is calculated to be the most cost-effective means of satisfying the transport demand. This will normally increase the supply of larger ships relative to smaller ships.

- Constant applies the existing (2010) fleet size proportions in every year to maintain a constant ratio of transport supply between different ship size categories.

It is recommended that for now, the “constant” option is selected as there are constraints that can affect the ‘optimal’ ship size which are not included in the algorithm at present.

Include retrofit and operational change allows the user to choose whether to include/exclude revision of the existing fleet. If the box is not checked then only newbuilds will be revised (fuel switching, design and operational speed, uptake of abatement options) and the existing fleet will not be modified in anyway. This is simply to allow the model to run faster in the instance that it is being used only for looking at how newbuild ships might change over time.

e) Output

This sets the run identifier. A unique run identifier can be used to allow multiple runs to be carried out with different input variables but for the same preprocessor input dataset, and then the outputs collated and compared.

3. Computation time

The computation time of GloTraM is a function of the input variables. A simple one time-step (e.g. 2010-2015) simulation with the most basic parameters will normally take approximately 30 seconds to run on a standard windows laptop. However, changing input parameters can significantly increase the run time. The following choices are of greatest significance:

Preprocessor choices:

- The run-time is linear in total number of time-steps taken for the simulation. A longer run (later end year or smaller time-step) will increase the run time.
- The time-step is also linear in size and age disaggregations. Selecting a size range file with more discrete sizes and reducing the time-step (which increases the number of age categories the fleet is broken down into) will increase the run time.

Model choices:

- The model is not highly sensitive to regulation scenario, but including more regulations will slightly increase the run time.
- The model is sensitive to investment horizon. A longer investment horizon will increase the run time.
- The model is sensitive to the number of main machinery and fuel options used. A larger number of options will increase the run time.
- The model is sensitive to the number of abatement options considered (fewer options = faster run time). To consider a smaller subset or remove any that do not ever appear economically viable then set the “use” variable to 0.
- The model is highly sensitive to the design and operating speed range settings. Increasing the range significantly increases the run time.

4. Inspecting GloTraM output data

For now, all output is presented in Microsoft Excel format. An individual run's output file can be found in: root\master model\data\outputs\"preprocessed input data". The "run identifier" specified in the model user interface is the name given to the individual output Excel files in this folder. A larger number of output variables are available for display, but for now the following are passed out of the matlab model to Excel (each with individual worksheets):

- **Trade data** includes the inbound, outbound and domestic trade mass flows for each of the regions used in the model.
- **Port call** includes the modelled estimates of the number of port calls for each of the ship size categories associated with the trade flow data (inbound, outbound and domestic).
- **Emissions data** includes the estimates of emissions for each of the regions modelled. This includes the emissions calculated according to transport demand (imp_te, exp_te and dom_te) and shipping activity (in_load, out_load, dom_load, dom_bal,). The former, allocates the loaded and ballast journey emissions associated with either the imports (consumption) or exports (production) transport demand of a specific region. The latter, specifies on the basis of shipping activity for the loaded and ballast movement of ships into, out of or domestic to the region. The total global annual emissions for that ship type and the cumulative annual emissions for that ship type are included at the bottom of the table.
- **Abatement options** specifies whether a specific abatement option is taken up by a given ship size category in a given year. If the value is zero it is not taken up, if a positive integer, it indicates the take-up prioritisation (e.g. 1 = most cost-effective option).
- **New ships** specifies the technical and performance parameters of newbuild ships in a given year.
- **Agg_fleet** specifies the average characteristics for ships in a given size range in a given year (across the ships of all ages in that size category).

Variable/region numbering used for the trade, port call and emissions data

1. Africa
2. Australasia
3. Central America and Caribbean
4. Europe
5. Indian Subcontinent
6. Middle Eastern Gulf, Red sea
7. North America
8. North East Asia
9. South America
10. South East Asia
11. UK

Emissions variables:

International shipping (a voyage of a ship from one country to another) is inherently difficult to apportion nationally. Bottom up methods which generate or utilise details of ship movements need a framework to enable consistent application across all regions to ensure fairness. It is important that such a framework should avoid double counting (apportioning any emission to more than one nation/region). One particular challenge to apportionment is how should emissions associated with a ballast voyage be allocated. Figure 11 shows four discrete types of voyage associated with international shipping, and two different approaches to apportionment:

- all inbound voyages (CCC)
- inbound loaded and outbound ballast (LCS)

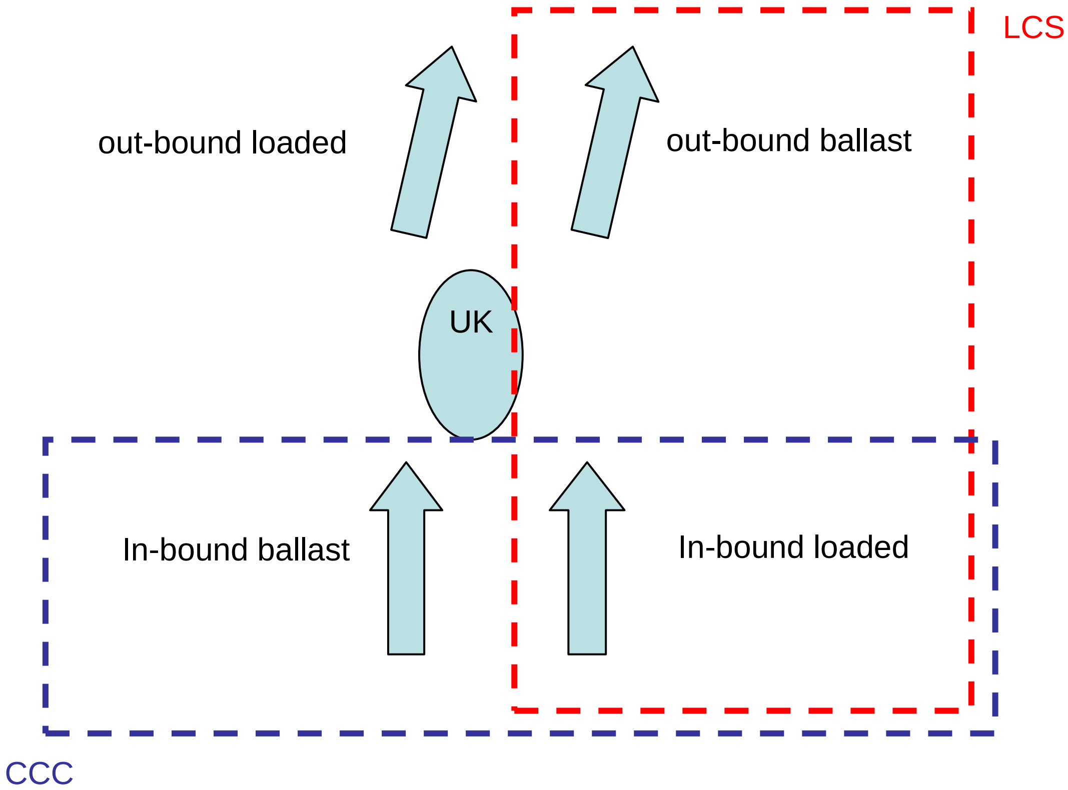


Figure 4: International shipping voyages associated with a country (e.g. UK)

GloTraM outputs data in order to enable both the LCS and CCC method to be applied. The LCS method calculates the emission as the product of the trade flow (imported, exported or domestic tonnenm) and the operational carbon intensity (EEOI CO2/tonnenm) of the ship type/size (imp_te, exp_te, dom_te).

The CCC method calculates the emission as the product of the total distance steamed on in-bound voyages and the carbon intensity per unit distance steamed of the ship type/size. The method calculates the emissions for each region from the four legs identified in Figure 4, and also for a further two domestic legs (loaded and ballast): (in_load, out_load, in_bal, out_bal).

Variable names used for the “new ships” worksheet:

teu – the teu capacity

dwt – the dwt capacity
build – the build year
P_me – the maximum power output of the installed main engine
P_ae – the maximum power output of the installed auxiliary engine
Fi_me – the fuel indicator (see below) of the main engine
Fi_ae – the fuel indicator (see below) of the auxiliary engine
V_des – the design speed
V_op_load – the average speed when loaded
V_op_ballast – the average speed when in the ballast condition
SOx spec – an indicator of what SOx treatment is implemented
NOx spec – an indicator of what NOx treatment is implemented
Rate_me_load – the average load (as % of MCR) of the main engine when at V_op_load
Rate_me_ballast – the average load (as % of MCR) of the main engine when at V_op_bal
Rate_ae_load – the average load (as % of MCR) of the auxiliary engine when at V_op_load
Rate_ae_bal - the average load (as % of MCR) of the auxiliary engine when at V_op_bal
Sfc_me – specific fuel consumption of the main engine
Sfc_ae – specific fuel consumption of the auxiliary engine
Loa – length overall
Beam – beam
Draught – draught
Lightship – estimated lightship displacement
Boiler_year – estimated consumption of fuel in boilers per year
Bw – an indicator of what ballast water treatment solution is implemented
Eta_p – the performance efficiency (the reduction in performance due to ageing/deterioration relative to a ship on its acceptance sea trial)
Me_spec – the main engine specification
Range – the estimated range of the ship at design speed
Eta_w – the average impact on performance efficiency of weather effects
Eedi – the calculated energy efficiency design index

Variable names used for the "agg fleet" worksheet also include:

Size – the number of active ships
Total – the total number of ships (active and laid up)
Trans_sup – the total transport supply from all active ships in that size category
Eeoi – the calculated energy efficiency operational index
H_load – the number of hours spent per year in the loaded condition
H_bal – the number of hours spent per year in the ballast condition
H_port – the number of hours spent per year in port or at anchor
CO2_year – the total CO2 produced annually by the average ship in that fleet
CO2_load_nm – the CO2 produced for every loaded nautical mile travelled
CO2_bal_nm – the CO2 produced for every ballast nautical mile travelled
CO2_total – the total CO2 produced from all the active ships in that size category

Fuel indicators:

values from 1-6 where 1 = HFO, 2 = MDO, 3=LSHFO, 4 = LNG, 5 = hydrogen, 6 = nuclear

Main engine specification:

Values from 1-5 where 1 = CI diesel, 2 = Diesel electric, 3 = SI LNG, 4 = FC hydrogen, 5 = nuclear